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CERES Operations for the Valencia *Anchor Station* in Support of GERB Validation Efforts. CERES SCALES Campaigns

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SUMMARY

The GERB (*Geostationary Earth Radiation Budget*) instrument launched in August 2002 on MSG-1 (*METOSAT Second Generation*) measures the energy emitted and reflected by the Earth.

Data from different satellite instruments are the only way to directly compare top of the atmosphere (TOA) data products, but direct comparison is not simple because the measurements depend on the viewing and the solar geometry, temporal and spatial sampling, the wavelengths measured and the spectral response of each individual instrument.

The similarity of the four CERES (*Clouds and the Earth's Radiant Energy System*) instruments to GERB's offers a suitable opportunity to intercompare their respective measurements and derived products. However, while GERB observes the Earth from a fixed position, the Terra and Aqua satellites on which the CERES instruments are mounted are in sun-synchronous, near-polar orbits, thus obtaining data from a variety of different viewing angles by scanning the surface. Because of this scanning mechanism, CERES and GERB measurements may be co-located, that is set to viewing the same point on the surface at the same time, but obtained from different view points, and therefore possessing different viewing and solar geometry. Detailed comparisons, at well characterized sites and involving other instruments also provide a simultaneous and independent measure of the accuracy of the two instruments. This is exactly the role that the Valencia *Anchor Station* (39º34'15''N, 1º17'18''W, 813 m altitude) tries to play. Its final objective is to characterize a large area about the size of a GERB pixel (around 50 x 50 km^2) situated in the natural region of the *Utiel-Requena Plateau*, in Spain, about 80 km West of the city of Valencia.

The main objective of the Spanish Space Research Programme Project SCALES (*SEVIRI & GERB CaL/VaL Area for Large-scale field ExperimentS*) is to develop a methodology for the validation of low spatial resolution satellite data and products mainly based on the use of the Valencia *Anchor Station*, around which 3D high resolution meteorological fields are obtained from the MM5 Meteorological Model. During the two *GERB Ground Validation Campaigns* developed so far at the Valencia *Anchor Station* (18-24 June 2003, and 9-12 February 2004), CERES instruments on Aqua and Terra provided additional radiance measurements to support validation efforts. CERES instruments operated in the PAPS mode (*Programmable Azimuth Plane Scanning*) specifically focusing the *Anchor Station*. Ground measurements were taken by lidar (June 2004 measurements), sun photometer, GPS precipitable water content, radiosonde ascents, *Anchor Station* operational meteorological measurements at 2 m and 15 m., 4 radiation components at 2 m, and mobile stations to characterize inhomogeneities of such a large area. These activities were carried out within the GIST (*GERB International Science Team*) framework, during the GERB *Commissioning Period*.

This paper describes the status of the methodology developed so far, the data obtained, and the application to the simulation of the specific CERES PAPS observations as a preliminary stage previous to the final interpretation of GERB products.

1. INTRODUCTION

The GERB sensor is the first instrument designed specifically to measure ERB parameters from a geostationary satellite. It is onboard the *METEOSAT Second Generation* (MSG) operational weather satellite, now renamed to Meteosat-8, and is providing accurate radiation measurements over a disc of the Earth every 15 minutes. In conjunction with narrow band measurements from the SEVIRI (*Spinning Enhanced Visible and Infrared Imager*) instrument, which is mounted on the same spacecraft, these measurements are currently processed to produce shortwave (SW) and longwave (LW) radiances and fluxes every 15 minutes at a spatial resolution of approximately 50 km.

There exists a consistent, two-decades-long Earth radiation budget data set established, based on measurements obtained from various instruments. By carefully validating instruments with respect to each other, such a set can be used for long-term climate studies. CERES instrument measurements have been part of this dataset since 1998. The GERB instrument measurements need to become a part of this set as well, as they offer unprecedented information about the diurnal cycle of heating and cooling of the Earth. In order to include its measurements, however, GERB radiances must be validated for their consistency with CERES instruments.

The main objective of the CERES/GERB campaigns is an attempt to establish the consistency between their measurements. In order to make a valid comparison of radiance measurements by two different instruments, it is important to match their viewing geometries at a given time instance. In addition to this spatial and temporal alignment, selecting homogenous energy sources to be measured is required for valid comparison. Despite the fact that LEO and GEO satellites Earth viewing geometries are quite different, it is possible to match them utilizing a unique feature of CERES scanners, so called *Programmable Azimuth Plane Scan* (PAPS) mode. This is accomplished by rotating the CERES scanning plane to align it with the GERB relative azimuth as the satellite flies over the GERB instrument visible portion of the Earth. There are no ideal energy sources to be measured by both instruments. Therefore, collecting a large amount of data for different scene types and averaging alleviates the problem of non-uniform radiation sources. In addition, the Valencia *Anchor Station*, a reference meteorological station for validation of low spatial resolution data and products, offers a place for cross-referencing measurements from different instruments, as its surface is reasonably homogeneous (Fig. 1).

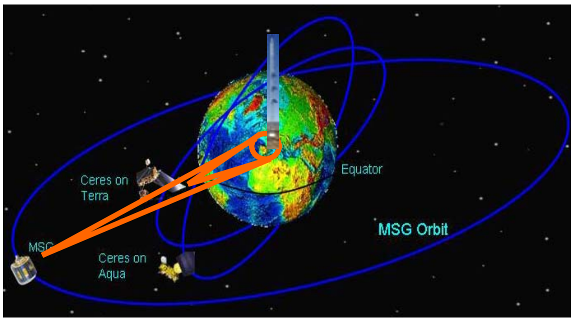


Fig. 1. Matching GERB (onboard MSG-1 EUMETSAT satellite) and CERES (onboard either Terra or Aqua NASA satellites) viewing geometries to simultaneously observe the same target on the ground (the Valencia *Anchor Station* in Spain)

The final goal of the validation exercise described here is to asses the quality, and as far as possible to quantify the accuracy of the GERB data products by comparing them with more accurate independent measurements of the same quantity over a statistically significant number of samples and wide variety of situations. It is never easy to meet these requirements. In the case of derived data products or geophysical parameters, such as, for example, surface temperature, which can be more directly measured on the ground than from satellite, the problem is not of making more accurate or independent measurements, but of obtaining a significant number and coverage. For GERB, where the products are TOA quantities, the most direct comparisons will be with other satellite measurements, and in this case, obtaining many and varied scenarios will only be a matter of time and opportunity. However, there is no instrument that directly measures the full range of outgoing radiances and fluxes without modifying them in some way. Therefore, a degree of modeling will always be required in the validation of these products which will compromise the independence of the quantities being compared Russell (2003).

The situation is further complicated by the matter of scale. GERB has a pixel size of approximately 50 x 50 km^2 and is designed to provide a measurement averaged over such an area. However, the surface and atmosphere is generally not homogenous over such scales and ground and aircraft measurements provide information at much smaller scales making it difficult to derive area averaged quantities from the ground.

To mitigate this problem, the results of each step in the processing chain can be assessed and different types of measurements used for validation. This necessitates differences in the modeling used to make the comparison. For example, a comparison with a broad band measurement will require a different approach than a comparison with a spectrum measured by an interferometer, or multi-channel radiometer observations. Similarly, comparing fluxes derived from radiances observed at different angles for similar scenes can help identify problems in the radiance to flux conversion that co-angular comparisons would not. Further investigations using ground and airborne measurements together with satellite data can also be used to further break down the uncertainties in the modeling process. This approach requires careful assessment of the various uncertainties involved in each component of the comparison, but examination of the differences between the results will help to provide a more independent assessment of accuracy and identify the processing steps responsible for significant discrepancies.

2. THE VALENCIA *ANCHOR STATION*

In many geophysical fields, the region of the Earth viewed by a satellite observation rarely matches exactly that viewed by the surface radiometer. Recourse must be made to statistical intercomparisons in order to reduce the sampling noise induced by the different space and time sampling characteristics of satellite and surface data. The special character of remote sensing measurements to correspond to area integrated values obliges independent *in situ* measurements to be representative of zones of a minimum number of pixels of the sensor under consideration. The large pixel size of satellite missions such as GERB and CERES, introduces a number of scientific issues that make it necessary to develop a specific methodology and carry out specific measurements over large areas.

This is the role the Valencia *Anchor Station,* established by the University of Valencia in December 2001, tries to play with the main objective of characterizing a reference Cal/Val area specifically dedicated to low spatial resolution Earth Observation missions. The site, defined within the natural region of the *Utiel-Requena Plateau*, at about 80 km W of the city of Valencia (39º34'15''N, 1º17'18''W, 813 m), represents a reasonably homogeneous area of about 50 x 50 km^2, mainly dedicated to vineyards, with the presence of other typical Mediterranean ecosystem components (shrubs, oaks, Alepo pine forests, olive and almond trees, etc) (http://www.uv.es/anchors and Fig.2).

Fig. 2. The Valencia *Anchor Station*

The relief is composed of generally plain (slope <2%) and slightly undulated regions (8%-15%), quaternary sediments surrounded by mountainous regions at the North and the East, and the Cabriel River basin in the Western and Southern boundaries of the plateau.

The soil types are calcic and haplic. The soils are deep with accumulation of carbonates and with low organic matter content. Specifically, over the *Anchor Station* the chemical composition of the soil is shown in Table 1 (A. Sanchis, Personal Communication).

Soil Texture at the Valencia *Anchor Station*. Brackets indicate particle size

	% Sand (0.05-2 mm)	% Silt (0.002-0.05 mm)	% Clay (<0.002mm)
1st horizon	47	38	15
2nd horizon	37	35	28

Climate: In spite of its relatively flat topography, the small altitude variations of the region clearly influence climate. This oscillates between semiarid in the areas of the towns of Utiel and Caudete de las Fuentes and dry – sub-humid towards Villagordo del Cabriel. The altitudinal differentiation between both climate types correspond to levels 800 – 850 m. Annual mean temperatures oscillate between 12 ºC of Villagordo del Cabriel and 14.2 ºC of Caudete de las Fuentes. Annual precipitation varies between 396 mm in Utiel and 451 mm of Caudete de las Fuentes and Villagordo del Cabriel. The duration of frost free periods is similar for the three town areas, from May to November. Maximum precipitation occurs in spring and autumn. The spring maximum is generally in May, whereas the autumn maximum is variable, in October for the areas of Caudete de las Fuentes and Utiel, and November for that of Villagordo del Cabriel.

In principle, the Valencia *Anchor Station* as such is a robust meteorological station where measurements are made at different levels both in the atmosphere and in the soil in order to be able to derive surface energy fluxes. The station is composed of two masts. One holds conventional meteorological instruments at 2 and 15 m high in the atmosphere, and –10, -20 and –40 cm in the soil. Air temperature is also measured at 0.5 m. The second mast is dedicated to measuring the four radiation components at 2 m above the ground. The station also has mobile instruments to measure specific parameters (atmospheric transmissivity, brightness temperature, vegetation parameters, soil moisture content, soil dielectric characteristics) and some meteorological quantities (air temperature and humidity, global irradiance, surface albedo, net radiation, soil temperature profile, soil heat flux) to account for inhomogeneities within the *Anchor Station* area. Other instruments are planned to be acquired in the short future to improve aerosol and cloud parameters validation.

3: THE CERES-GERB GROUND VALIDATION CAMPAIGNS AT THE VALENCIA *ANCHOR STATION*

Two ground validation campaigns have so far been carried out at the Valencia *Anchor Station* during GERB's *Commissioning Period*. The first one was developed from 18th to 24th June, 2003. In addition, measurements were also carried out for 14th and 30th June, LANDSAT-7 ETM overpassing days over the study area. Detailed description of the campaign and of the measurement dataset obtained can be found in Lopez-Baeza et al., (2003 and 2004a).

The second ground validation campaign took place from 9th to 12th February 2004, and was designed by looking for the coincidence of observations from other satellite instruments with different spatial scales (Fig. 3). The dates were also chosen such that either CERES on Terra (9th February) or on Aqua (12th February) were observing the Valencia *Anchor Station* with the highest elevation angle so that the PAPS scans were almost on a perfect along-track mode over the station (Fig. 4).

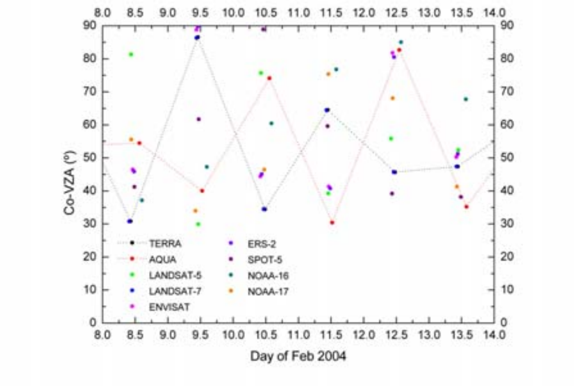


Fig. 3. Diagram showing the coincidence of observations of the different satellite systems indicated over the Valencia *Anchor Station* between the 8th and the 14th of February, 2004. The Y-axis shows the satellite elevation angle (co-VZA, complementary of the viewing zenith angle). This wide variety of observation angles from different remote sensing instruments with different spatial scales provides a valuable database of radiances to estimate the BRDF at different scales (J.F. Gimeno-Ferrer, Personal Communication)

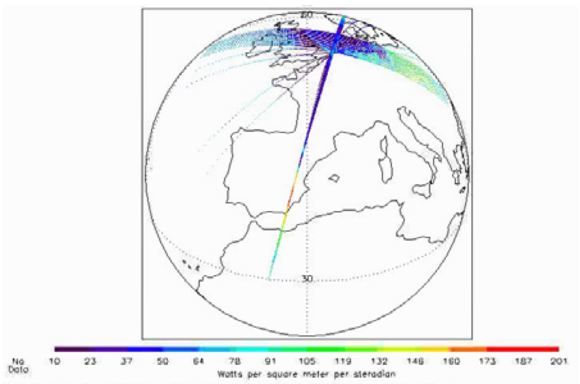


Fig. 4. Along-track observation of CERES (shortwave) onboard Terra over the Valencia *Anchor Station*, 9th February 2004.

The methodology that is currently been developed to obtain ground independent values of some geophysical parameters at GERB scale has also been introduced earlier (Lopez-Baeza et al. 2004b). Basically, we use data from the *Anchor Station* together with measurements from GPS to calculate precipitable water content, from a sun-photometer to calculate atmospheric transmissivity and aerosol optical depth, and from radiosonde ascents, specifically obtained over the *Anchor Station* and simultaneously to CERES overpassing times. Two mobile meteorological stations help us to account for inhomogeneties by measuring some parameters in other regions of different characteristics to those of the *Anchor Station*. We also use 3-D high resolution simulations (1 x 1 km^2) from the MM5 meteorological model as a robust interpolation tool to obtain atmospheric fields over the whole region. We are presently applying this methodology to reproduce TOA CERES radiances as a very convenient intermediate step between ground measurements and GERB observations.

4. APPLICATION EXAMPLE: SIMULATION OF CERES OBSERVATIONS ON 10TH FEBRUARY 2004 OVER THE VALENCIA *ANCHOR STATION*

Simulation of Longwave and Shortwave Radiances

In order to be able to reproduce CERES observations it is necessary to have a good characterization of the surface and of the atmosphere. The literature is full of references that show that the TOA radiances are sensitive to the anisotropy of surface reflectance and of its diurnal variations. Thus, it is crucial to know surface spectral albedo and bidirectional reflectance.

As an application example, we shall centre out attention on the simulation of 10th February 2004 at 13:20 h. This was a clear sky day over the Valencia *Anchor Station* area, without clouds and where the presence on aerosols was not quite significant (Fig. 5)

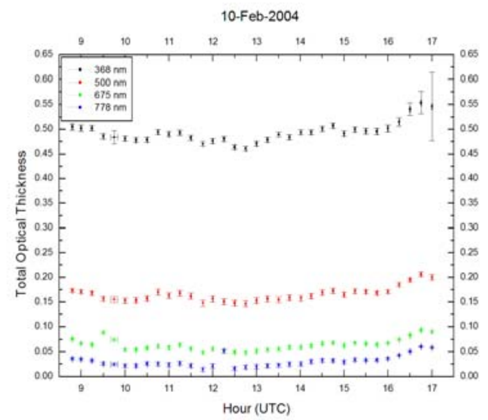


Fig.5. Evolution of total optical thickness at the Valencia *Anchor Station* on 10th February 2004 (J.F. Gimeno-Ferrer, Personal Communication)

To start our study, let us assume that the surface equivalent to the CERES pixel under consideration corresponds to bare soil since the area, although mostly dedicated to vineyard crops, in winter the situation actually corresponds to bare soil. As a consequence, we shall first be using a Bidirectional Reflectance Distribution Function (BRDF) from the literature corresponding to bare soil (Ahmad and Deering, 1992). This BRDF has been calculated from a model based on the scattering physical laws, uses Hapke's (approximation, includes an empirical term to explain the hot spot and uses Cox and Munk (1954) formulation to take specular reflection into account.

The physical parameters used by the model have been obtained from bidirectional reflectance measurements.

The model provides hemispherical bidirectional reflectances for bare soil every 10º of Solar Zenith Angle (SZA), 10º of Viewing Zenith Angle (VZA), and 30º Rotating Azimuth Angle (RAA) for two different spectral bands, namely the red at 0.662 μm and the near-infrared at 0.826 μm.

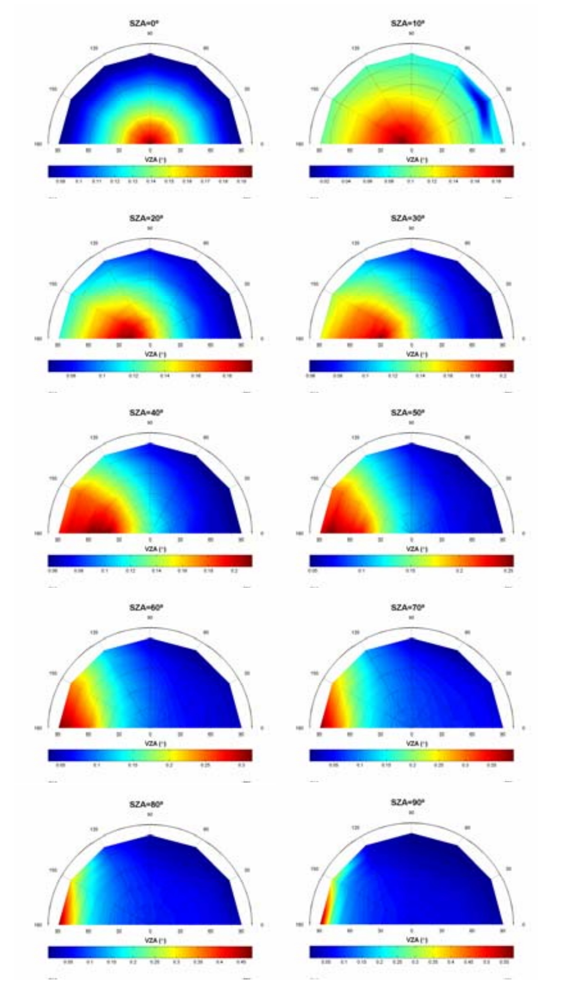


Fig. 6. Bidirectional reflectance distribution function (BRDF) at 0.662 μm. The radial axis corresponds to the different VZAs, the polar axis corresponds to the different RAAs, and every diagram corresponds to a different SZA. For the near-infrared band, the graphs are very similar.

In order to adapt this BRDF model to our conditions, we scale spectral reflectance using the *Anchor Station* broad-band albedo (α = 0.27) as a normalization condition. The spectral reflectance used has been obtained from the ASTER spectral library of John Hopkins University (http://speclib.jpl.nasa.gov/). Thus, we can obtain representative values of spectral reflectance for the average SZA during CERES overpassing conditions (θ_0 = 55.87 degrees) in the bands needed by the BRDF model, namely 0.662 and 0.826 μm. The BRDF thus obtained for each SZA in the red band is shown in Fig. 6.

The scaled BRDF is then introduced in the STREAMER (Version 3.0b7) radiative transfer model (Key and Schweiger, 1998) with which we carry out the simulation of CERES TOA shortwave and longwave radiances for 10th February 2004 at 13:20 UTC. Other input data used in the simulations were:

- Surface emissivity (ε = 0.987) obtained from the CERES/SARB surface information (http://www-surf.larc.nasa.gov/surf/). See also Wilber et al. (1999)
- Surface temperature (T_S = 289.5 K) measured at the Valencia *Anchor Station*
- Aerosols: background tropospheric, 50 km visibility, and background stratospheric amounts
- Total precipitable water content obtained from the corresponding radiosonde ascent: 2.79 g cm^{-2} which also compares very well with the GPS measurements (Fig. 7)
- Ozone concentration from TOMS: 6.66 g m^{-2}

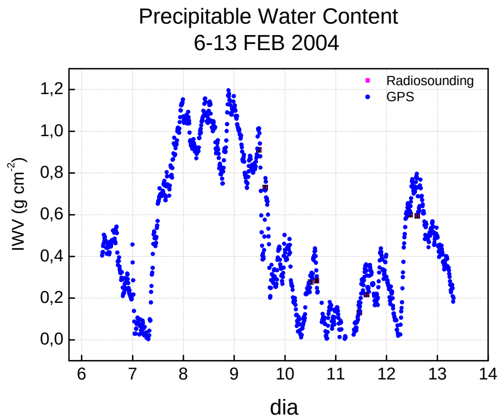
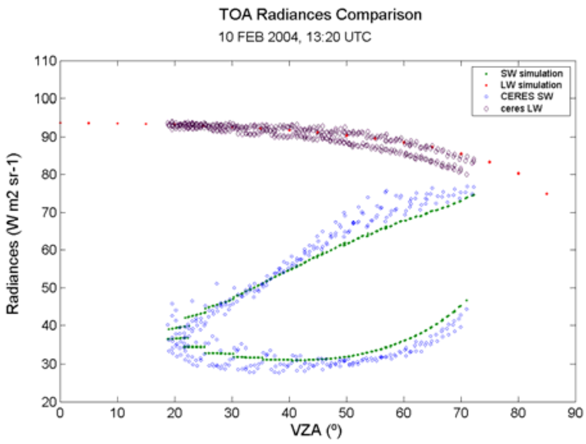


Fig. 7. Precipitable water content estimated from Zenith Tropospheric Delay measurements obtained at the GPS receiver (in blue) installed at the Valencia *Anchor Station* which compares very well with radiosonde ascents (red dots) specifically sent at CERES overpassing times from the station as well

The final results of the shortwave and longwave simulations are shown in Fig. 8 for 10th February 2004. The graph gives the TOA radiance as a function of CERES VZA, where we can see that there is a good match between CERES radiance observations and simulated radiance values obtained with all the justified assumptions and input data indicated. We consider this a good result which gives us good expectations for when we extend this methodology to GERB pixel size and were the use of the MM5 meteorological model will be crucial.



5. CONCLUSIONS

We have been able to reproduce CERES TOA radiances (shortwave and longwave) obtained from special PAPS scans over the Valencia *Anchor Station* by means of radiative transfer simulations powered by accurate ground and atmospheric measurements. This is a good step forward towards the similar exercise to be carried out next on simultaneous GERB data at a much lower spatial resolution (50 x 50 km^2).

The immediate improvement of this work will be to consider the variety of land uses present in the study area with their respectively measured spectral reflectances to obtain accurate BRDFs under these conditions.

The Valencia *Anchor Station* seems to be a very convenient site to carry out validation activities of low spatial resolution remote sensing instruments. Its equipment is adequate, the site is reasonably homogeneous at that scale, and the activities currently developed increased the knowledge and characterization that are needed of the area. The expected upgrading of the instrumentation with a ceilometer, a total sky imager and a sun tracking photometer certainly will increase the possibilities of validation of more parameters related to clouds, aerosols and radiation.

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